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Packet Radio Temporary Note No. 41

Richard A. Shepherd
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April 13, 1973

PRELIMINARY NOTES ON MAN-MADE NOISE AND PACKET RADIO

One of the requirements to be met by the packet radio net is to operate in urban/suburban areas. These areas, by definition, contain many sources of man-made noise including automobiles, power lines, etc. The purpose of this note is to explore the implications of attempted network operation in such a noise environment and to recommend some measurements needed for system design.

Very few measurements of man-made noise have been made at the frequencies being considered for the PRN. Most of these have been measurements of the average noise level as seen through a voice-bandwidth filter. Some average pulse rate measurements as a function of level have been made at frequencies up to 460 MHz in the vicinity of highways and industrial areas but with narrow bandwidths.

It has never before been particularly important to make wideband man-made noise measurements because there have never been wideband omnidirectional radio systems operating in urban areas in a manner which would expose them to man-made noise. Existing systems are either narrowband (such as land mobile), highly directional (such as microwave relays), or one-way broadcast such as television. Man-made noise certainly bothers the latter in fringe areas, but the development of more TV broadcasting and cable facilities have been rapid enough to assure that very few receivers are in fringe areas.

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Very few measurements of man-made noise have been made at the frequencies being considered for the PRN. Most of these have been measurements of the average noise level as seen through a noise-bandwidth filter. Some average pulse rate measurements as a function of level have been made at frequencies up to 450 MHz in the vicinity of highways and residential areas but with narrow bandwidths.

It is not known to be particularly important to make broadband noise measurements because there have never been any commercial radio systems operating in urban areas in a manner vulnerable to man-made noise. Mobile systems are either (1) operated from fixed locations (such as taxicabs), (2) highly directional (such as microwave links), or (3) very broadcast (such as television). Man-made noise is definitely nowhere the factor in rising areas, but the development of operating and cable facilities have been rapid enough to limit many fee receivers are in fringe areas.

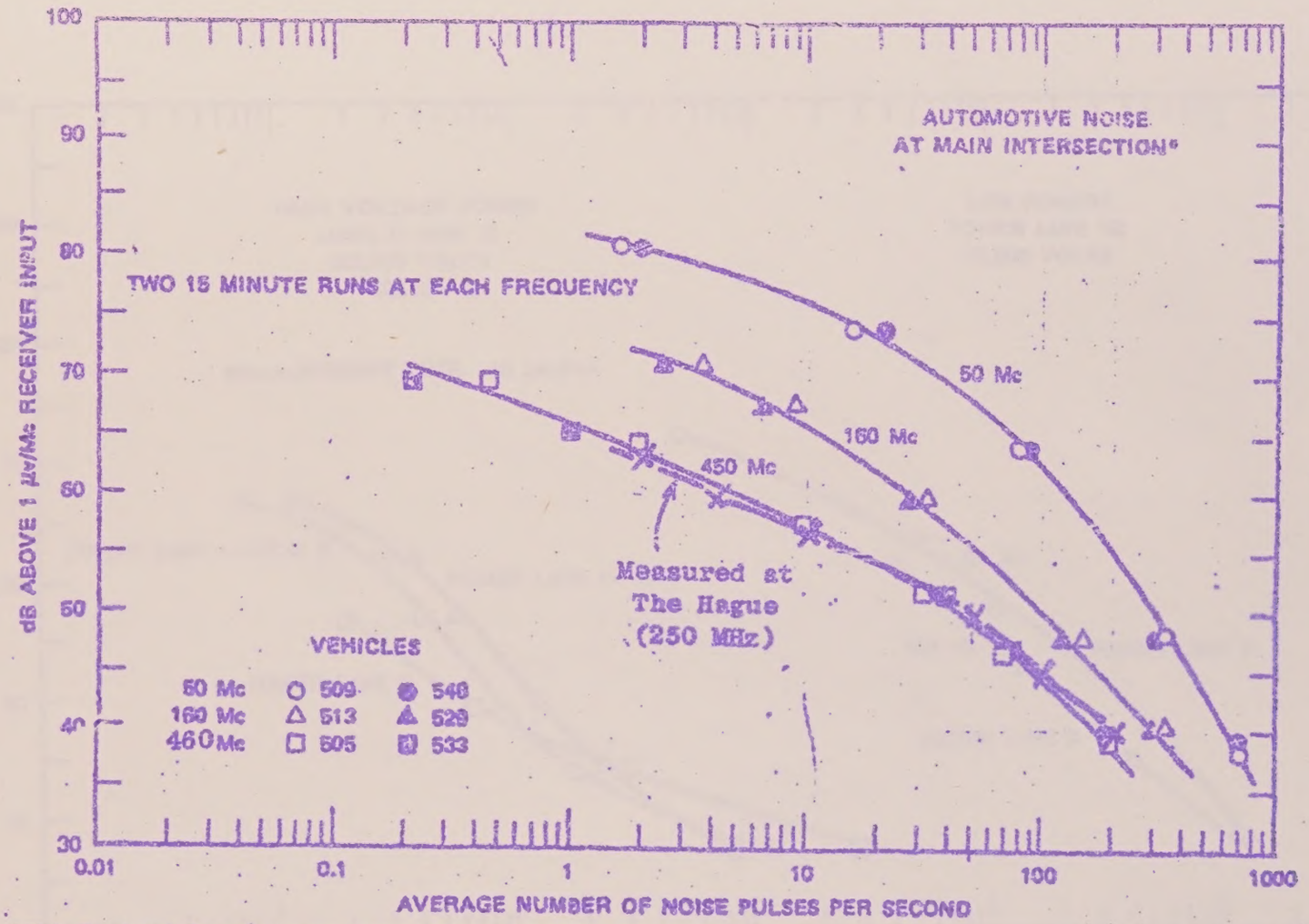
The PRN, however, may be very seriously hampered by man-made noise, and some detailed measurements are certainly in order before the design is completed and prototype development begun.

Measurements of single sources show that man-made noise is highly impulsive and that this characteristic is retained at least up to 6 GHz. HF measurements (30 MHz) of compound sources (a modern expressway with 15-50 cars per minute) show that the impulsive nature exists for these sources also.[1] Measurements by Deitz[2] (Figures 1 and 2) show the mean noise pulse rates as a function of pulse amplitude for a number of urban and suburban environments in the Washington D.C. area at frequencies up to 460 MHz. Similar measurements, made at 250 MHz by Oranc[3] in the vicinity of a satellite ground terminal in the Hague, indicate the same behavior of pulse rate as a function of amplitude, but neither has been concerned with more refined statistics of the pulse occurrences.

Figure 3 indicates the number of ignition pulses from an "average" vehicle at 460 MHz relative to the pulses at typical locations and relative to receiver noise and suggests that high pulse rates might be very common.

Suppose that we expect to operate a packet radio near (within 200 feet of) some reasonably busy street. Then the passing automobiles will generate significant noise and will probably be the primary noise sources. As an automobile passes the radio terminal each spark discharge will generate at least one* noise impulse. At 3000 rpm, an 8-cylinder

*Some measurements at SRI[1] indicate that a second pulse often follows each main pulse by a millisecond or less.



*Blair Road and Georgia Avenue, Silver Spring, Maryland.

SOURCE: Dietz (1967).

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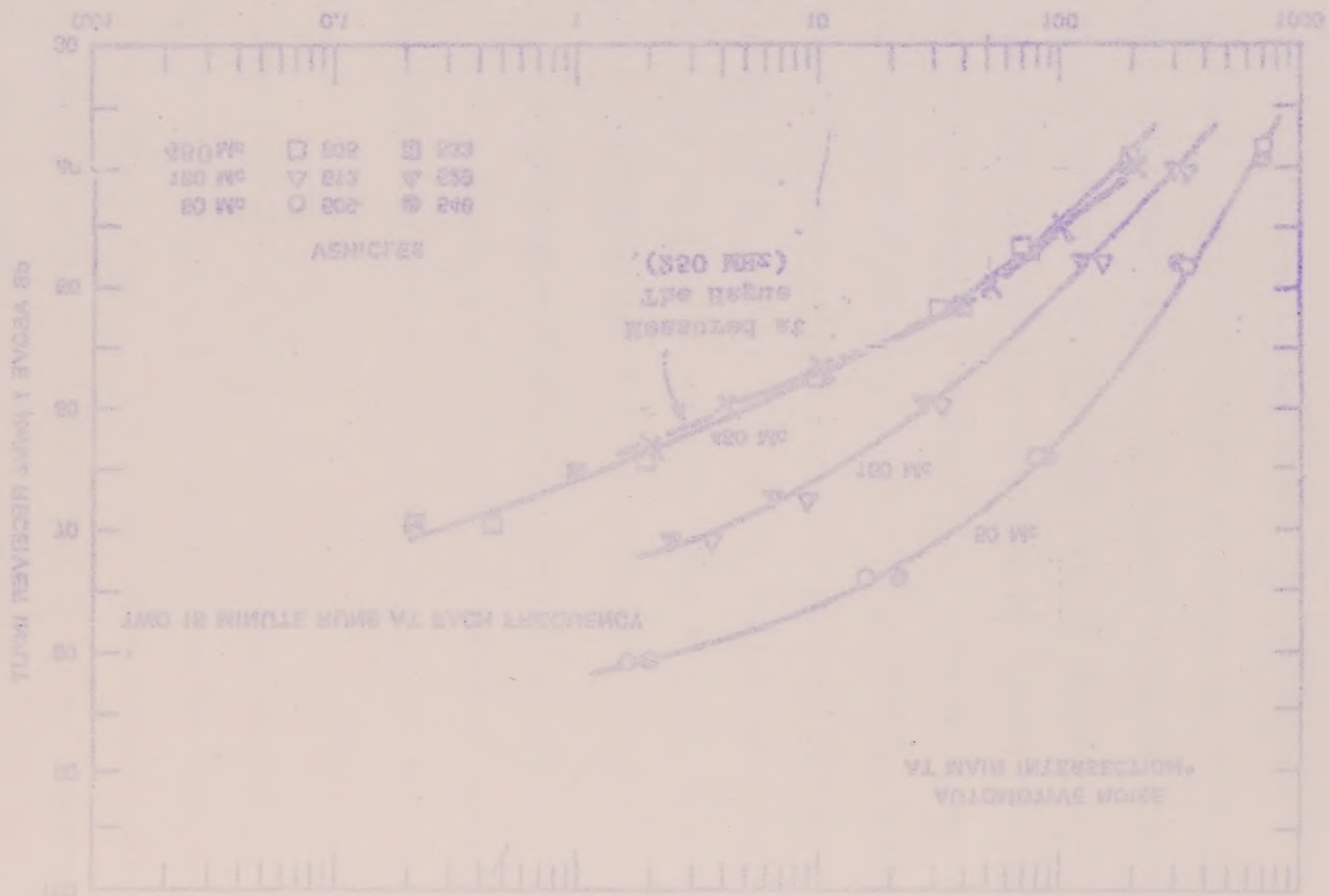
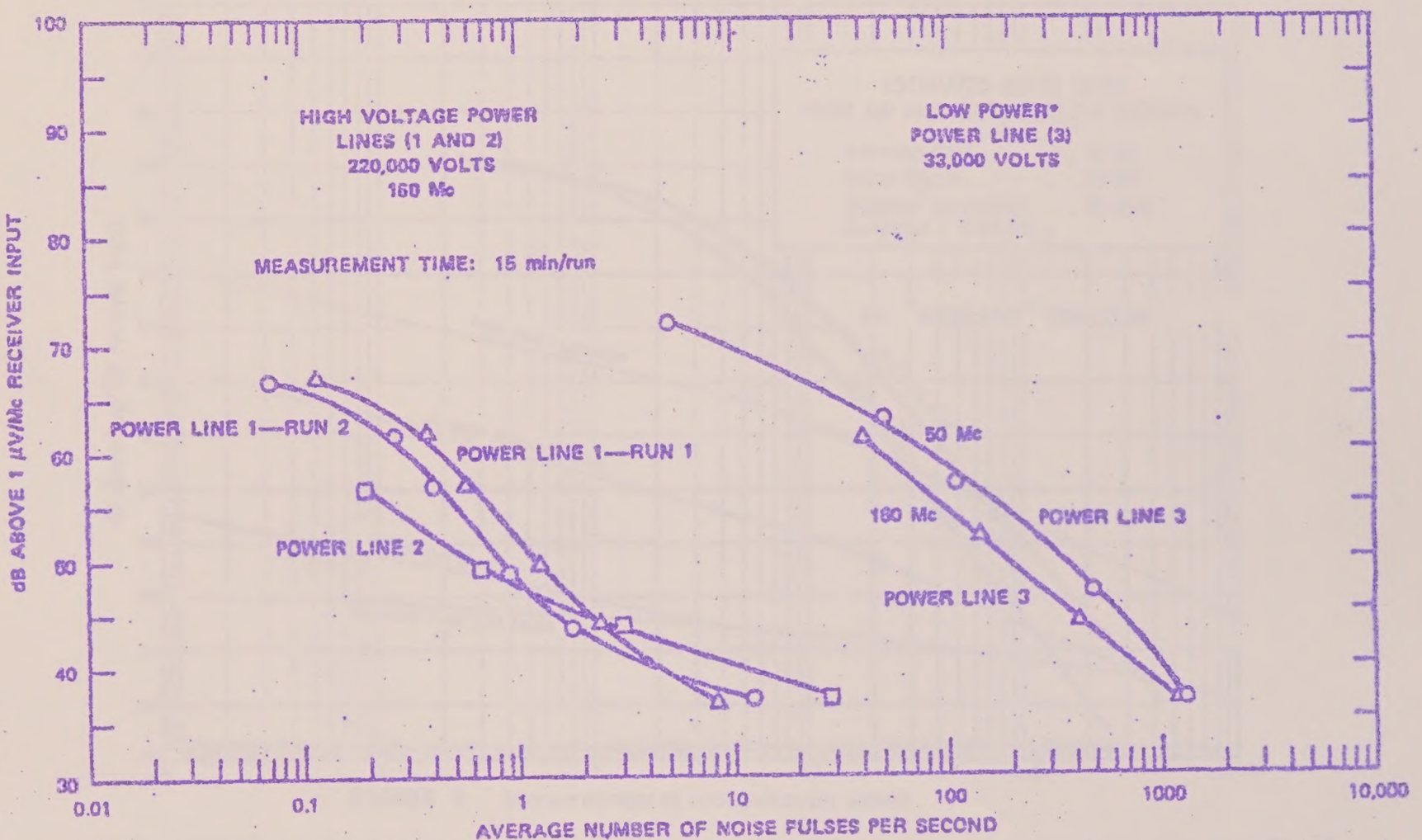
FIGURE 1 AUTOMOTIVE NOISE TAKEN AT A MAIN INTERSECTION





*Georgia Avenue, St. Catherine's Church, Silver Spring, Maryland.

SOURCE: Dietz (1967).

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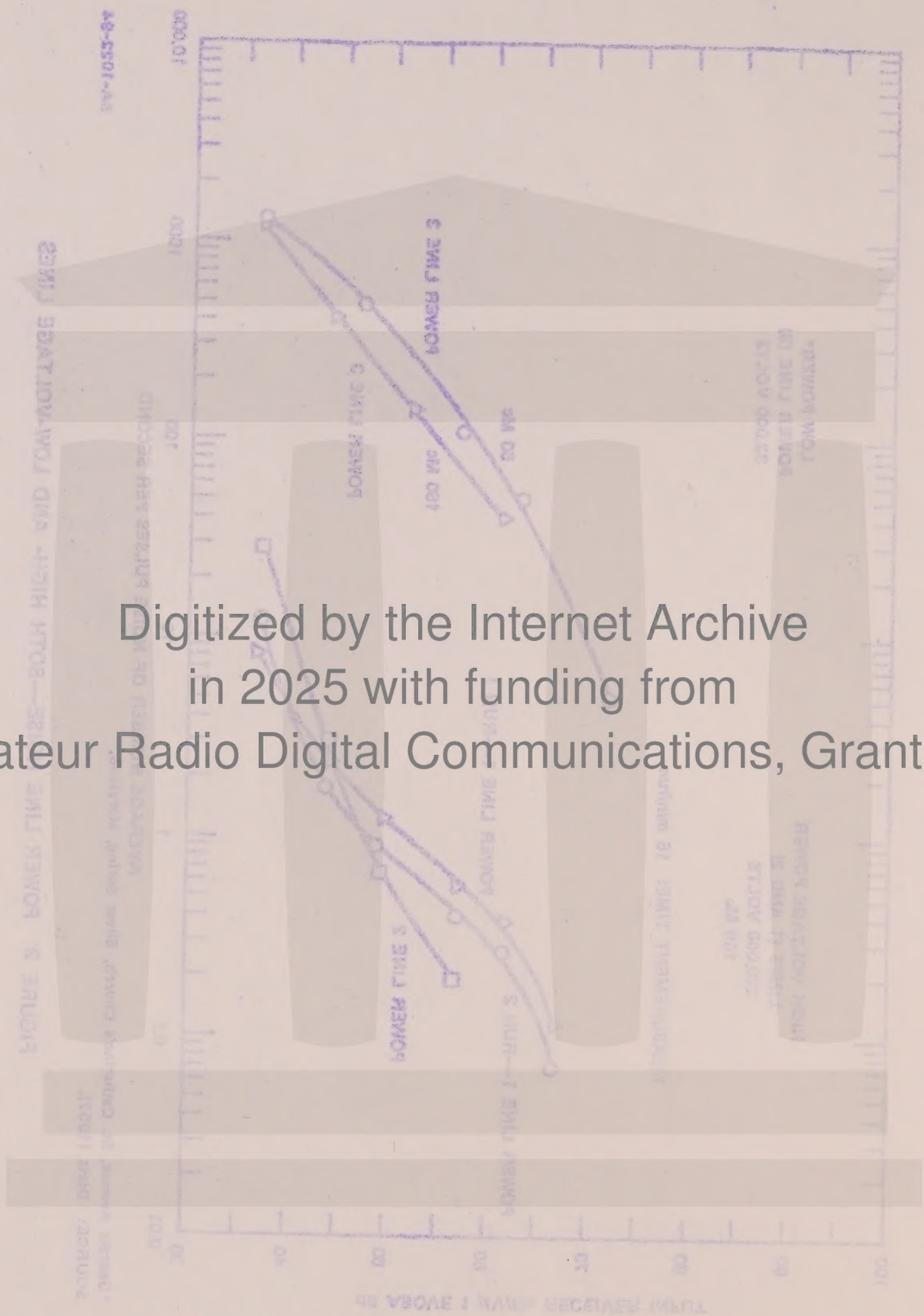
FIGURE 2 POWER LINE NOISE—BOTH HIGH- AND LOW-VOLTAGE LINES



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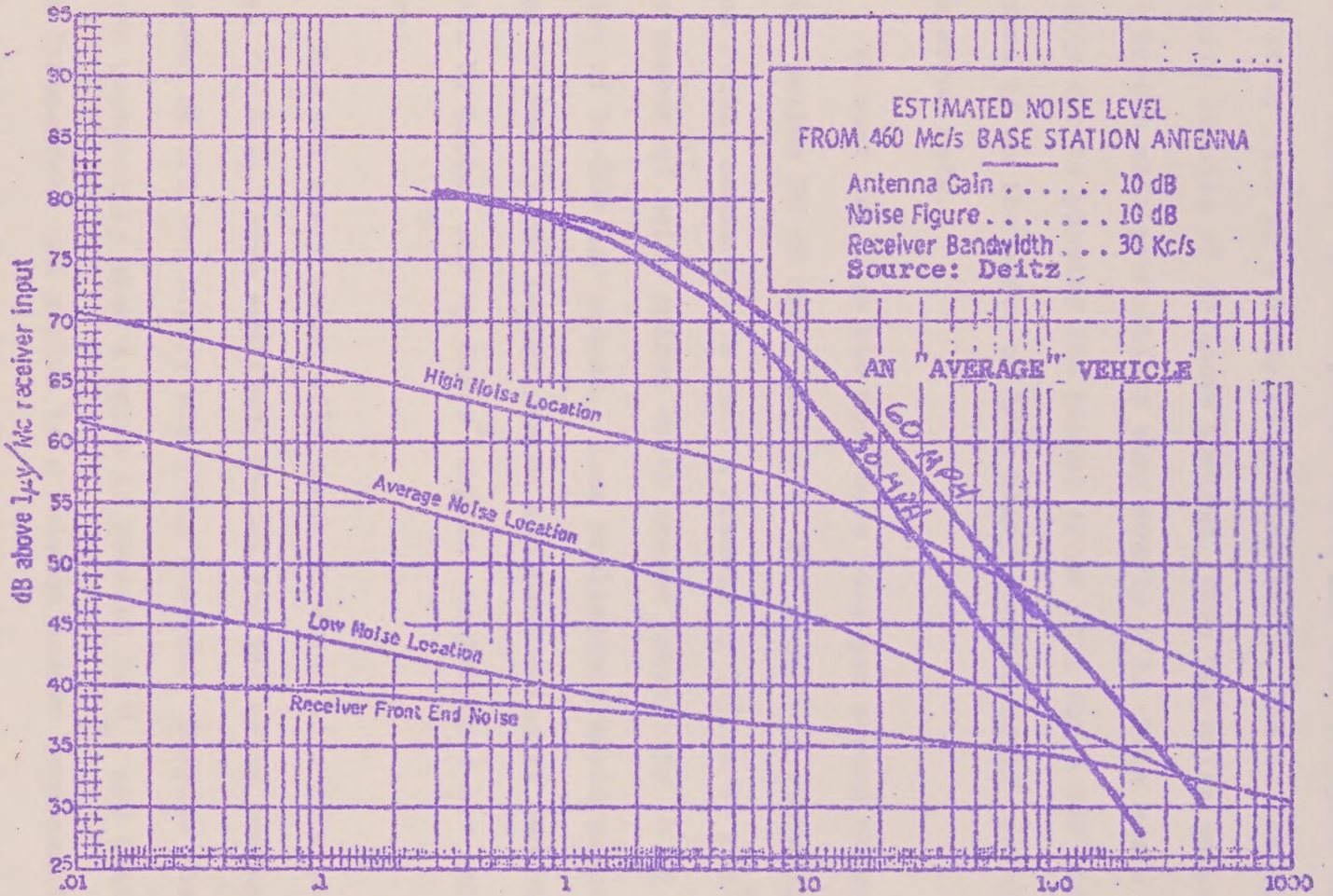
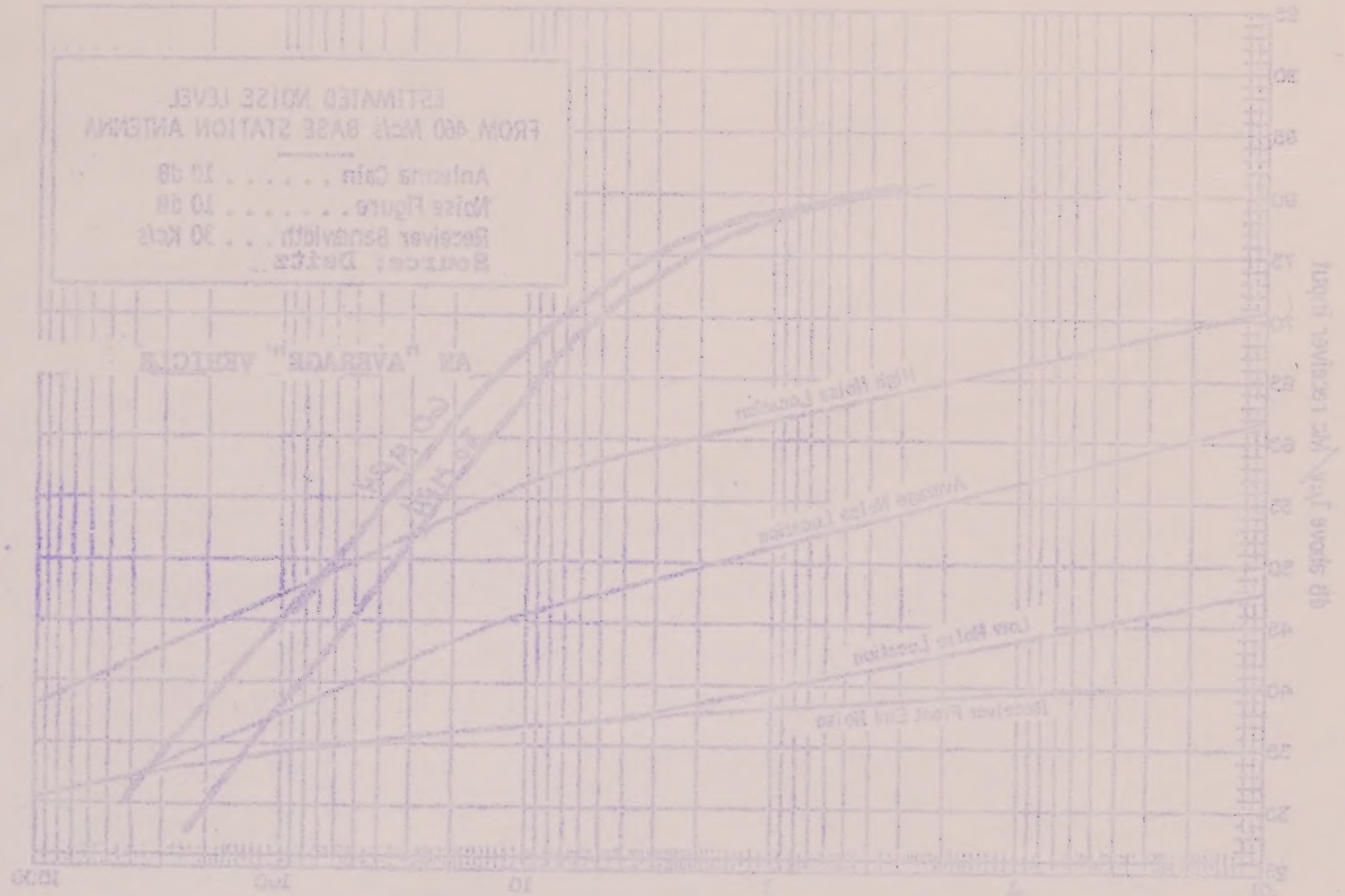


FIGURE 3 Average number of noise pulses per second



engine will generate a spark discharge once every 5 ms. Thus, there will be at least one discharge for every 500 bits (at an assumed 100 kBps rate). If the packet radio has been designed for an acceptable bit error rate in a Gaussian ambient noise, and if the discharges cause a noise impulse 20 dB above ambient, then the noise spikes will cause bit errors with probability very nearly 1/2. This means that when a single car is passing the packet error rate for a 250 bit (received) packet is on the order of 1/4; heavy traffic would presumably increase the error rate.

We must ask then how many cars pass per second which generate noise spikes 20 dB above ambient? The answer is unknown; however, some recent measurements near a freeway by SRI at 30 MHz[1] show that the number of noise spikes which exceed ambient by 10 dB is on the order of 35-200 per second. Some preliminary measurements at Hawaii tend to verify the importance of man-made noise at 400 MHz. Measurements by Deitz[2] and by Orenc[3] neglect to indicate the ambient noise level.

Now not every pulse will cause an error in a data packet; in fact, even for very large amplitude pulses the bit error probability will be bounded by 1/2 for binary signaling schemes. Suppose that the bit error probability when a pulse is present is P_p, and that the pulses are independent and arrive in a Poisson manner (exponentially distributed interarrival times). Then when there are i pulses in a packet the bit error probability will be $1-(1-P_p)^i$. If $P_i(t)$ = probability of i pulses per packet of duration t, then the probability that

the packet is in error is

$$P_e = \sum_{i=1}^{\infty} P_i(t) \left[1-(1-P_p)^i\right] .$$

Under our assumption of noise pulses being Poisson distributed with mean λ pulses per second,

$$P_i(t) = \frac{(\lambda t)^i e^{-\lambda t}}{i!}$$

and

$$P_e = 1 - e^{-\lambda P_p t} .$$

Thus the effect of the random amplitude and random phase of pulses can be accounting for by scaling λ the average pulse rate, by P_p. The value of P_p will vary depending upon modulation techniques and signal levels, but will never exceed 1/2. In fact, we can obtain a lower bound on P_e by setting $P_p = 1/2$. Figure 4 shows the probability that a 10-ms packet is not affected by noise pulses for three assumed values for P_p and over a range of mean pulse rates that have been observed by various experimenters. It indicates that impulsive noise may seriously degrade the system and that we need to know more about the pulse rates and their effect on the packet's individual bits.

Several models have been proposed for man-made noise. Most of these are adaptations of models for atmospheric noise, which has an impulsive characteristic similar to man-made noise. The model which

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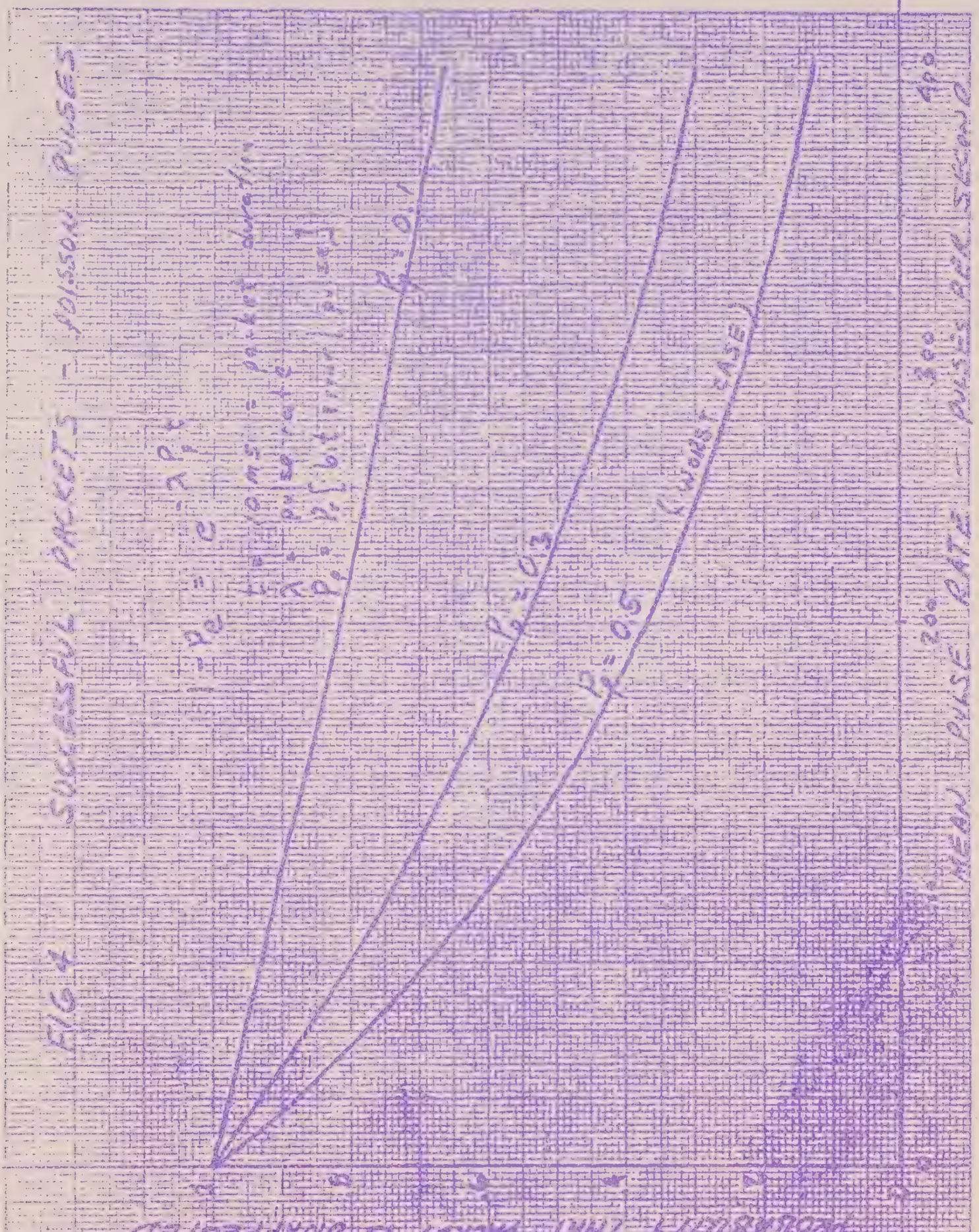

seems to be most useful for packet radio is one which represents the noise as a filtered impulse train:

$$n_m(t) = \sum_i \alpha_i \, \delta(t-T_i) * h(t)$$

where the α_i and T_i are random variables and the filter impulse response h(t) represents the effects of both channel and receiver. This model is physically appealing since most known man-made noise sources generate impulses which are large compared to the background noise.

In order to obtain the pulse amplitude and timing information indicated above in the frequencies of interest to the PRN, measurements will have to be made. These measurements should be performed at the locations planned for testing or for the ultimate operation of the PRN. Typical urban and suburban situations should be selected for noise measurements as well as spots near highways and streets and in the vicinity of power lines.

At these locations the ambient noise power relative to thermal noise should be measured using omnidirectional antennas of the sort to be used in the PRN. Since the imposing feature of the compound radio noise at these high frequencies is expected to be its impulsive behavior, an experiment should be designed to provide detailed statistics on the particular parameters of impulsive noise which will bear upon the operation of packet radio. One of the measurements must yield

the distribution of the pulse peak amplitudes so that improved estimates of P_p, the conditional probability of a bit error given the occurrence of a pulse, can be developed. Statistics of pulse arrival rates beyond simple means should be gathered so that reasonable models of interpulse intervals can be derived. Studies of the interarrival time dependencies should be made, for surely there will will be grouping of the pulses as noisy automobiles pass near a receiving site and the interarrival times will be more nearly a constant determined by the rpm of the engine than a random variable.

We urge that a man-made noise measuring experiment be fielded without delay so that the noise environment in which the Packet Radio Net must operate will be more thoroughly understood than it is at present. Knowledge of the noise to be encountered will allow the design of the system to proceed with greater confidence.

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2. Jules Deitz, "Man-Made Noise," Report to Technical Committee for Land Mobile Radio Services (FCC) from Working Group 3 (June 1966).

3. H. S. Oranc, "A Study of Impulsive Noise and Measurements in the VHF/UHF Bands," Thesis (?) Submitted for Promotion to Associate Professorship at Middle East Technical University, Ankara, Turkey (July 1972).